Involuntary Biases of Attention in Visual Search

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Summary

In this thesis I address the idea that involuntary biases of selective attention play a part in motivating adaptive, expert behaviour. We and other animals are primed to repeat actions that have led to good outcome: we are likely to pluck a berry from a bush in part because this action has been rewarding in prior experience. I demonstrate that this principle applies to the cognitive processes that precede action, and particularly to the way the brain processes visual information. We are good at plucking berries in part because our prior experience – and particularly our prior experience of reward - has primed us to notice and attend to berry-like objects.

It is important to note that when I refer to the deployment of attention in this thesis this has little to do with movement of the eyes. In all the experiments described participants are instructed to maintain eye fixation while completing the experimental task, and only results observed when participants could suppress eye movements are reported. I am interested in *selective attention* - the cognitive mechanism that enhances some aspects of the visual environment without movement of the eyes.

Many of the experiments described in this thesis investigate the ability of salient stimuli to automatically capture attention to their location. With this in mind the concept of attentional capture is introduced and reviewed in Chapter One. Even after some twenty-five years of research, there is a lively debate on this topic and I discuss and review some of this work. I also suggest that prior experience – and the quality of this experience - plays a central and perhaps undervalued role in determining how attention is deployed.

In investigations of attentional capture the idea that visual objects compete for representation has proven to be a productive conceptual framework. This idea is perhaps best exemplified by the *biased competition hypothesis* of Robert Desimone and John Duncan. According to this proposal, the inhibitory relationship of cells in visual cortex instantiates a process in which visual representations compete for resources. Biases in this competitive interaction can be automatically created by raw stimulus salience, but can also be strategically created such that an advantage is given to objects that will help us achieve our goals.

Chapter Two describes two experiments that investigate how the prior experience of visual stimuli influences the competitive interactions between visual representations.

Participants complete a *visual search task* where they are instructed to search for a target that is presented alongside a number of distractors, one of which is rendered salient by unique color. In one experiment this salient distractor can be defined by a color that has recently characterized the target. Under these circumstances competition is fierce: the distractor strongly interferes with the neural representation of the target, and this becomes evident in participant behaviour. In a second experiment the distractor is always characterized by the same color. Under these circumstances competition changes: the distractor only interferes with the target representation when it is very close in space, and when both stimuli are presented in the same visual hemifield. This suggests that prior experience with the distractor gives participants the ability to reduce the impact of raw stimulus salience, but not to diminish it entirely.

Chapter Three continues the investigation of attentional capture. In this study electrical brain activity is recorded from electrodes placed on scalp surface while participants complete a competitive visual search task. Event-related potentials (ERPs) are extracted from this electrophysiological signal, and a specific component of the visual ERP – the N2pc – is identified.

Much of the research described in this thesis relies on the N2pc, so it deserves some description here. The primate visual system is organized such that visual input from each half of the visual field is processed in the opposite hemisphere of the brain. When attention is applied to an object in one half of this field, this changes the electrical activity created over the visual cortex that represents this field. This can be indexed in the ERP as an increased negative potential over the visual cortex contralateral to an attended object (relative to the signal over ipsilateral visual cortex). We can use this signal to determine whether visual attention is deployed to the left or right half of the visual environment.
Chapter Three demonstrates that a salient distractor can elicit an N2pc, even when participants know to ignore this object. This suggests that attention can be captured by very salient stimuli.

Chapter Four extends these results. Participants complete a competitive visual search task while ERPs are recorded. The results are examined as a function of *intertrial contingency*. That is to say, trials were binned according to whether the colors characterizing the target and salient distractor were the same as they had been in the immediately preceding trial, or whether they had swapped such that the target was characterized by the color that had previously defined the distractor and vice versa. Results show that the distractor elicits an N2pc when that stimulus has the colour that recently characterized the target. This suggests that distractor salience is in part a product of prior experience. Attention is biased towards objects with visual features that have defined targets.

Chapter Five tests the hypothesis that capture occurs when attention is rapidly deployed. Visual representations appear to develop over time, becoming more sophisticated as higher-level information is integrated. Representations are thus coarser earlier in time, and raw visual salience is more strongly represented. If attention is deployed quickly, during the time that salience is well-represented, it may be that salience plays a greater role in determining how attention is deployed. In this study trials were binned as a function of participant reaction time, resulting in the definition of a condition where participants responded very quickly and a condition where participants were slower to select the target. The results showed that when participants were fast to respond, the N2pc elicited by the target was large in amplitude - reflecting strong target selection - and the N2pc elicited by the distractor was very small. In contrast, when participants were slow to respond the distractor-elicited N2pc was large and early. The rapid deployment of attention thus ironically causes slow response latencies, as participants have to correct themselves and redeploy attention to the target.

Chapters Six through Eight build on the idea that attention is deployed to objects with visual features that have recently characterized targets. These studies were motivated by the idea that this might reflect the underlying influence of reward. Participants find it rewarding to select the target and correctly complete the experimental task, and as a result the features that define the target become reinforced. This causes objects with similar features to become perceptually salient.

Much of this work relies on ideas stemming from the *incentive salience hypothesis* of Kent Berridge and Terry Robinson*.* Drs. Berridge and Robinson suggest that the fundamental function of the reward system is to motivate animals to detect and approach environmental stimuli that are likely to provide reward. This is in part instantiated through perceptual and attentional priming.

If priming in visual search reflects the underlying influence of reward then explicit manipulation of reward should modulate the priming effect, and Chapter Six was designed to test this hypothesis. Participants complete a visual search task where a salient distractor competes with a target for selection. At the end of each correctly completed trial they received a reward, either 1 point or 10 points, and they were paid based on the number of points they accumulated through the experiment. Importantly, this reward was completely random, and thus not based on any characteristic of the visual stimuli or of the participant's response. The results show that people respond quickly when the same colour characterizes a target as did so in the immediately preceding trial, but only when that preceding trial garnered high-magnitude reward. In contrast, when they received high-magnitude reward but the colours swapped between trials, so that the distractor came to be defined by the colour that had previously characterized the target, responses became slower. ERP results show that the distractor elicits an N2pc under these circumstances, demonstrating that the distractor captures attention when it is characterized by a reinforced colour.

The study reported in Chapter Six additionally examines the ERP response created by reward feedback. A component known as the medial frontal negativity (MFN) is isolated. This component is thought to reflect activity in a specific part of the brain – the anterior cingulate cortex (ACC) – that is part of a network that processes reward outcome. Source localization of the MFN elicited confirms that it reflects ACC activity, and the magnitude of this activity is found to predict the behavioural effect of reward on visual search. In other words, participants with a large ACC response to reward are those that are more likely to attend to the distractor when it is characterized by a reward-associated colour.

What does it mean for ACC activity to predict the impact of reward on visual search? One possibility is that this ACC activity indexes the importance that people place on reward. Reward is a stronger motivating factor for some than others, and it may be these reward-driven personalities show a large ACC response to reward feedback.

Chapter Seven investigates this possibility. Participants complete the same visual search task as was employed in Chapter Six, but fill out a personality assessment before starting the experiment. One measure on this test indexes the degree to which reward drives behaviour. Results show that those participants who score highly on this measure – those for whom reward is a strong motivating force – are also those who show a large impact of reward on visual search.

Reward's impact on visual search could come about in one of two ways: reward could prime the representation of the target, or it could facilitate our ability to ignore distractors, and Chapter Eight addresses this issue. Rather than having both target color and distractor color vary from trial to trial, in this study either target color or distractor color is selectively varied in separate experiments. This allows for the impact of reward on targets and distractors to be examined discretely. Reward is found to benefit target selection and make it hard to subsequently select a distractor, but, surprisingly, it does not appear to make a distractor any easier to ignore.